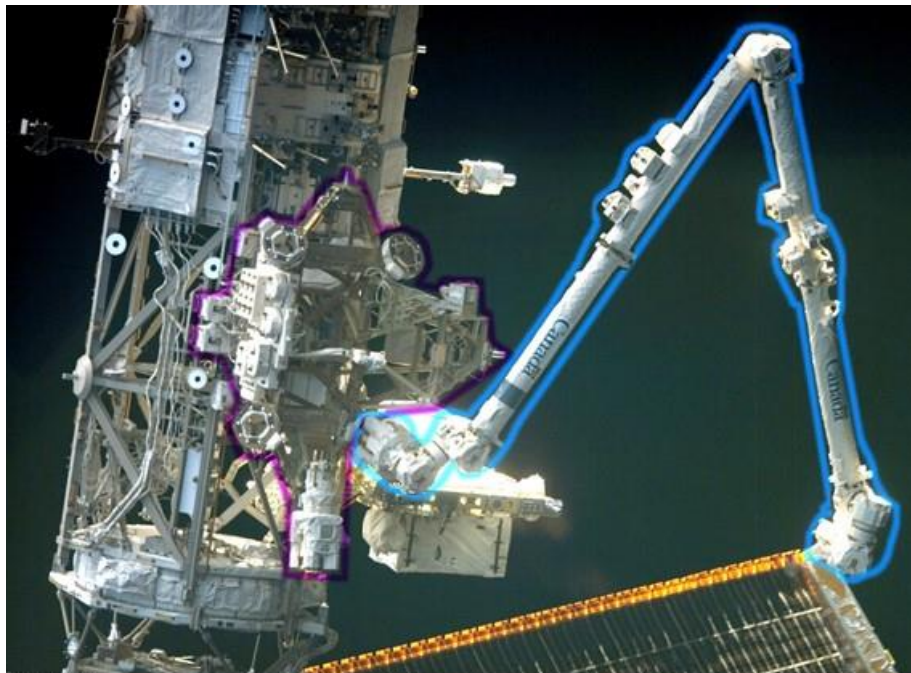


Robotics on the International Space Station (ISS) and Lessons in Progress

Monica Visinsky, Ph.D.
Senior Staff Engineer
Oceaneering Space Systems

- Space Station Robotic Manipulator System (SSRMS) – launched 4/2001
- Special Purpose Dexterous Manipulator (SPDM) - launched 3/2008
- Japanese Experiment Module (JEM) Remote Manipulator System (JEMRMS) – launched 6/2008
 - Main Arm (MA)
 - Small Fine Arm (SFA)
- Robonaut – launched 2/2011, legs launched 8/2014
- *ESA Robotic Arm (ERA) – planned late 2017*

- The SSRMS is a 17m/56 ft long arm weighing ~1500kg/3300lbs
 - Consists of seven joints for seven Degrees Of Freedom (DOF)
 - SSRMS can officially carry ~21,000kg/46,300 lbs (could go more)
 - Joints are configured as two identical clusters separated by an elbow pitch with a Latching End Effector off the last joint of each cluster
 - This allows either end of the SSRMS to be attached to ISS as the base
 - Three locations on ISS modules
 - Four locations on corners of the Mobile Base System (MBS)



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SSRMS on MBS



SSRMS on Node2 Capturing Cygnus

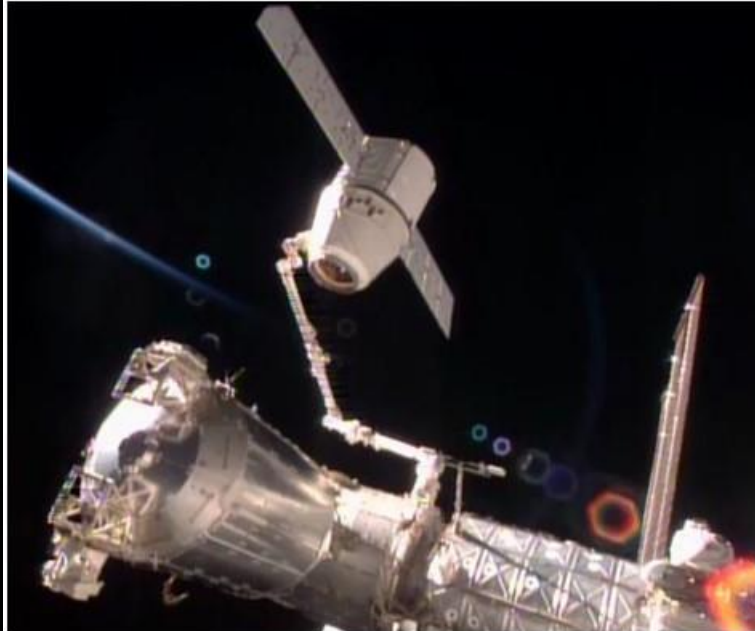
- SSRMS was used to perform ISS assembly tasks
- Captures visiting vehicles: Space-X, Cygnus, H-II Transfer Vehicle (HTV)
- Utilized as 'cherry picker' support for EVA or robotics
- Performs some external cargo deploy operations



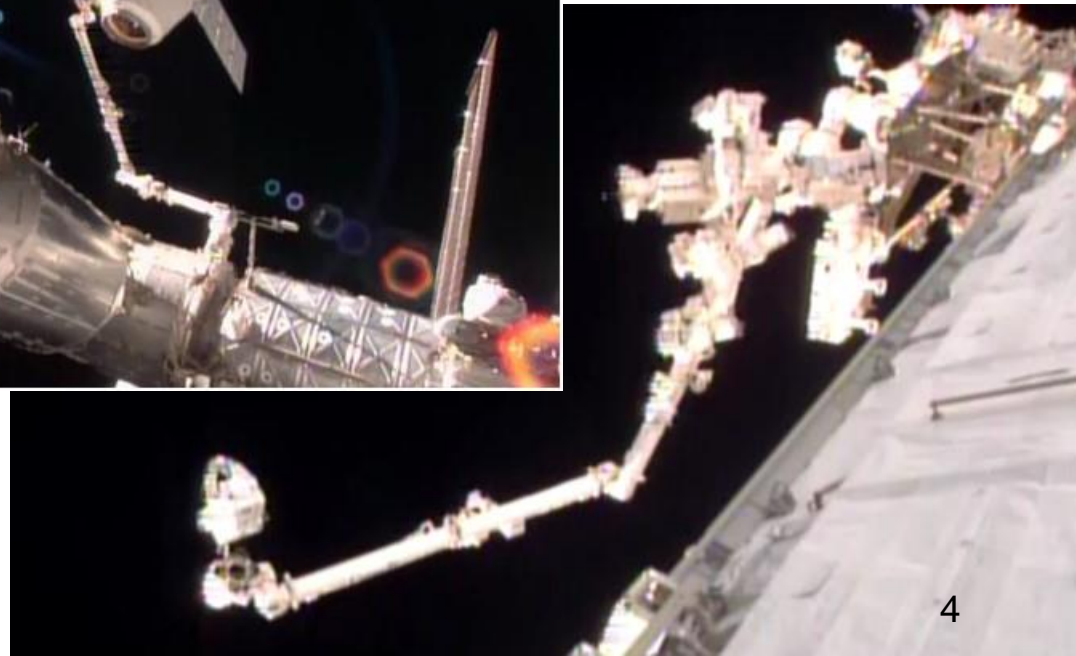
Assembling ISS

March 2017

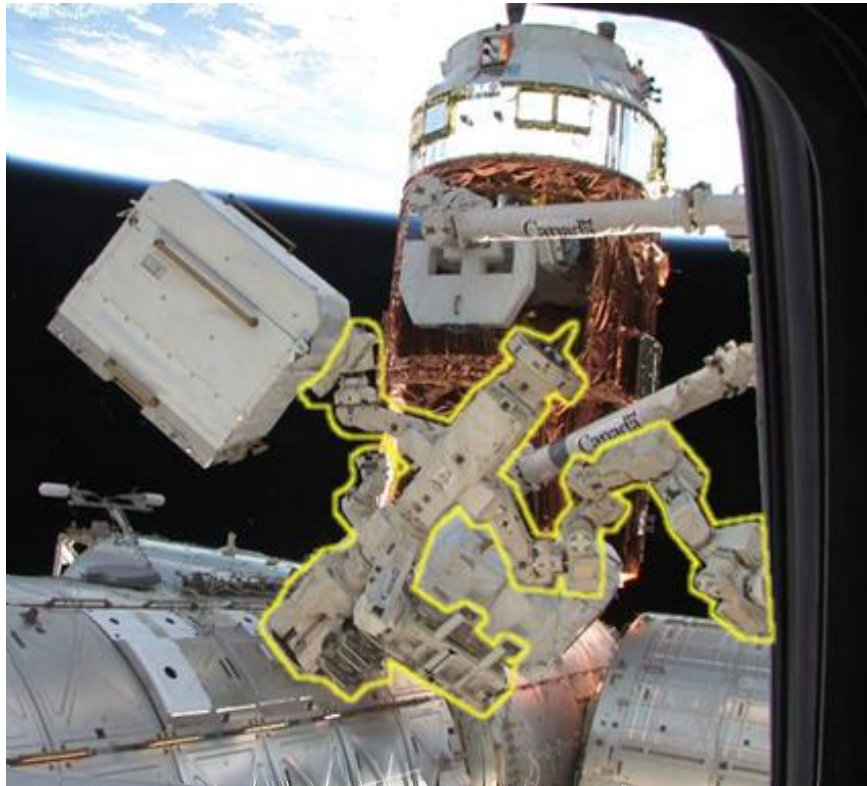
Capturing Dragon



Supporting EVA



- SPDM (Dextre) is a two armed robot with a 3.6m/12ft tall body weighing ~1770kg/3900lbs
 - Each arm is 7 DOFs, 3.4m/11ft long extended, and can carry ~600kg/1320lbs
 - Body roll allows access to 3-sided temporary storage and tools
 - Can be based on modules, MBS, or SSRMS



SPDM on Lab (holding cargo)



SPDM on SSRMS (reaching into Dragon)

- SPDM was primarily designed to perform external maintenance on ISS (originally for 250 external components)

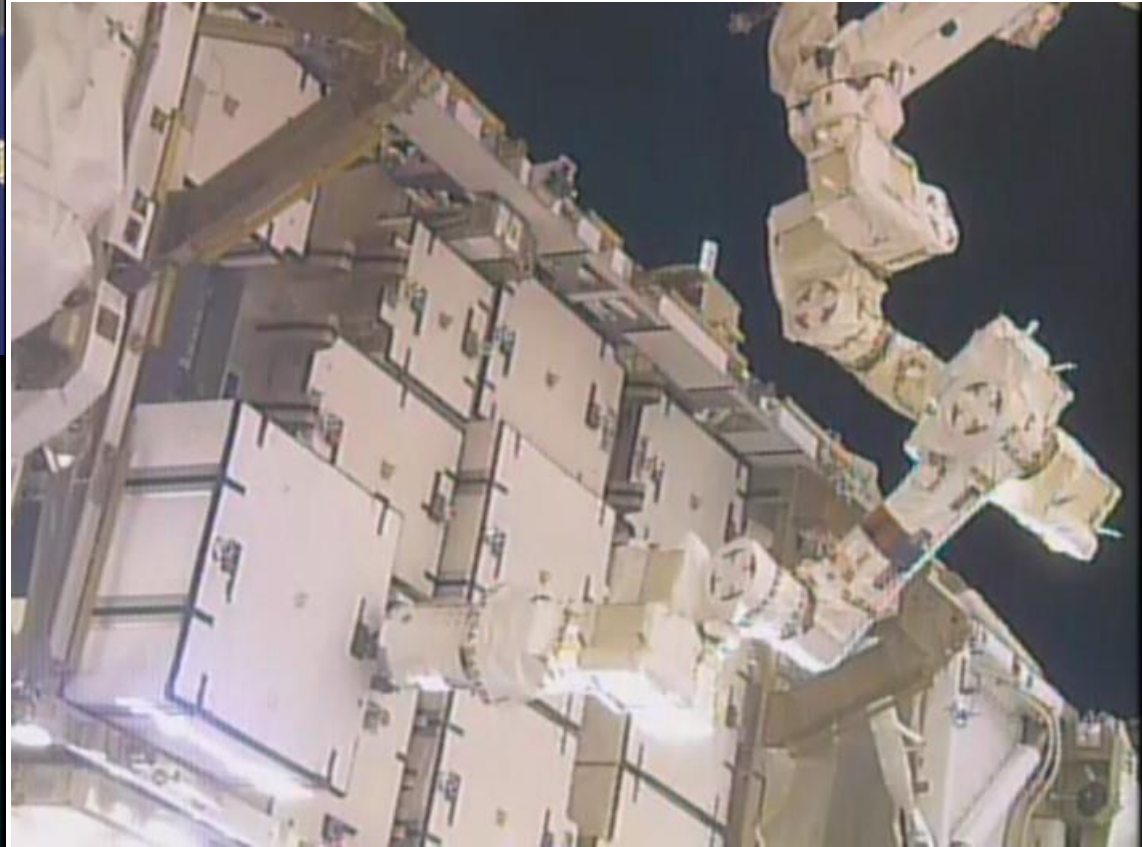


Maintenance of ISS power switch box

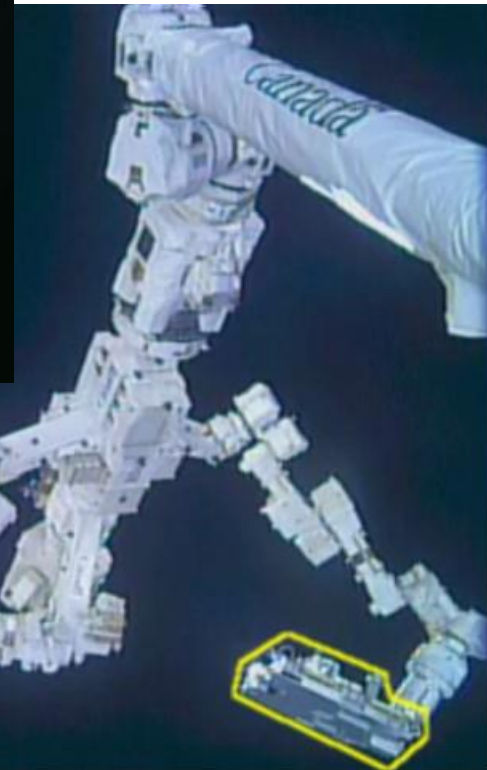
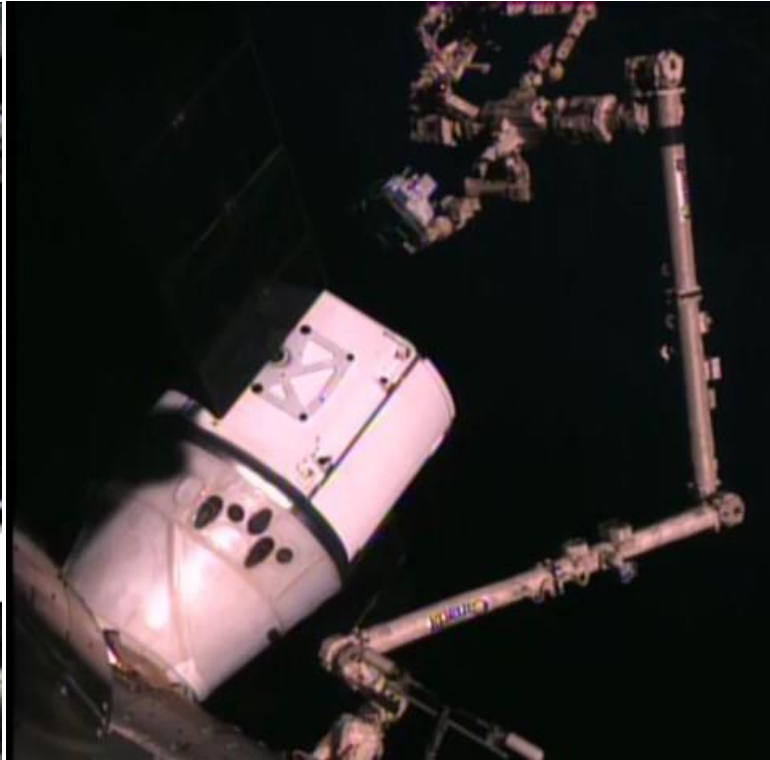


Maintenance of SSRMS camera

- Also utilized to deploy cargo from visiting vehicles, perform surveys, and assist in various science payload tasks



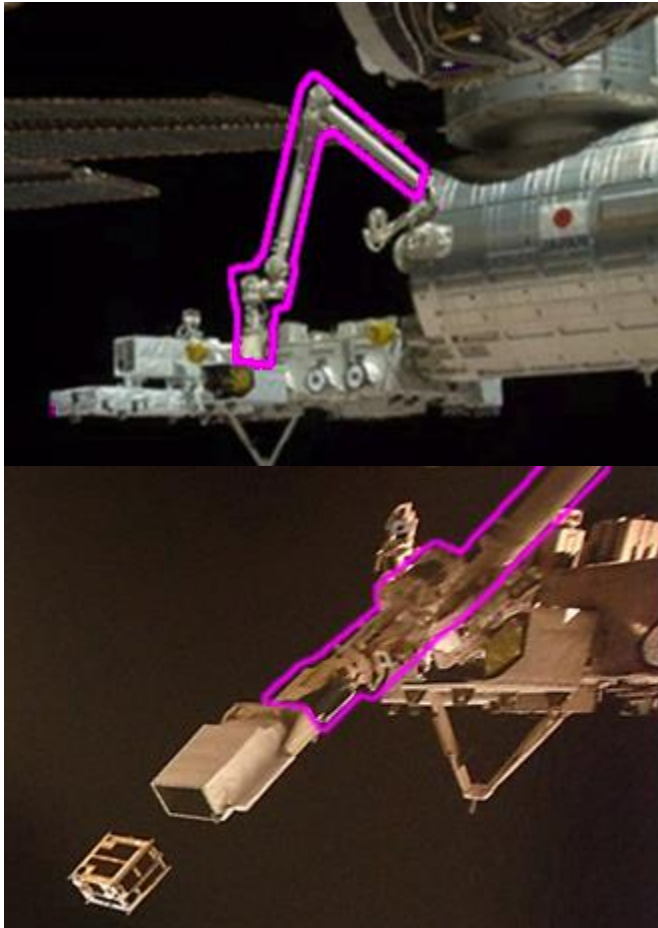
**HTV6 transfer of 6 new Lilon batteries to replace 12 old NiH2 batteries
(18 days of robotics!)**



**Space-X 10 transfer of 3 experiment pallets to ISS/disposal of 3 pallets back to Dragon
(20 days of robotics!)**

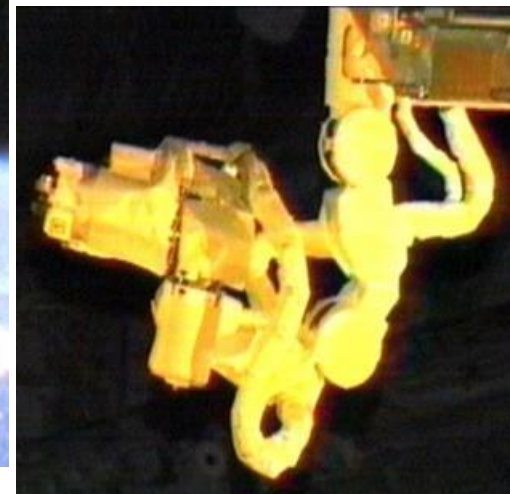
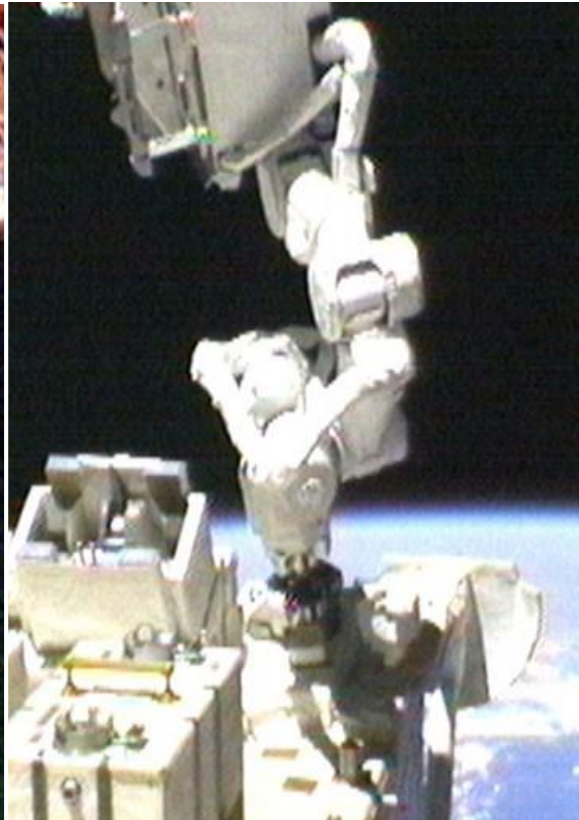
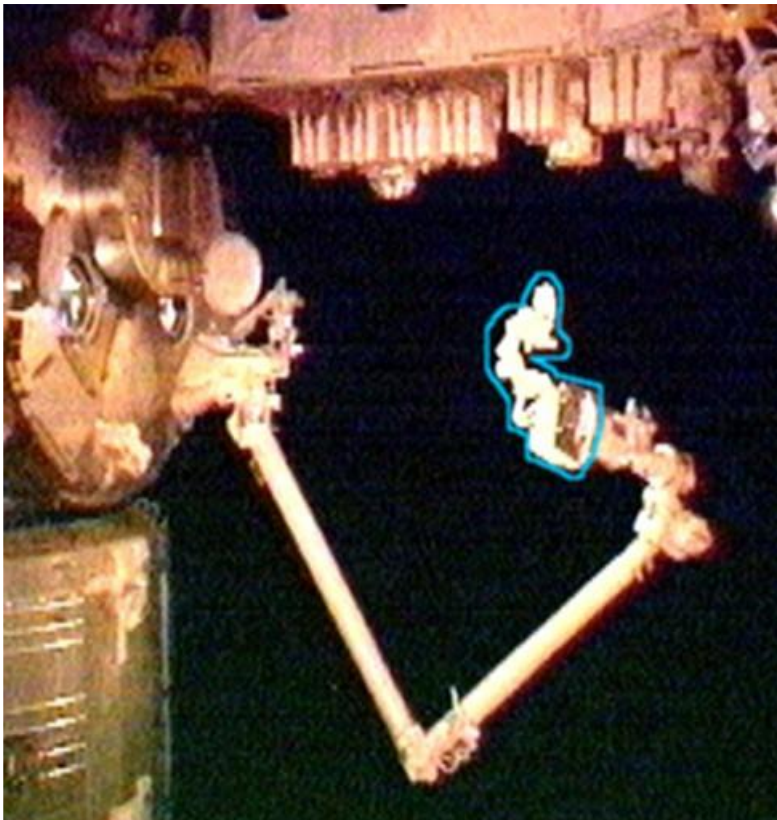
March 2017

- Main Arm is a 6 DOF arm attached to Japanese Experiment Module and can reach to JEM Exposed Facility (EF) region (~7.6m/25ft reach)
- Used to install experiments or pallets to JEM EF and provide a base to deploy satellites brought out via the JEM Airlock Slide Table



March 2017

- Small Fine Arm is a 6 DOF arm that can be picked up by the Main Arm as a more dexterous extension (~0.6-1m/2-3ft reach)
- It can be used to interact with payloads on JEM EF or transferred outside via the JEM Airlock Slide Table



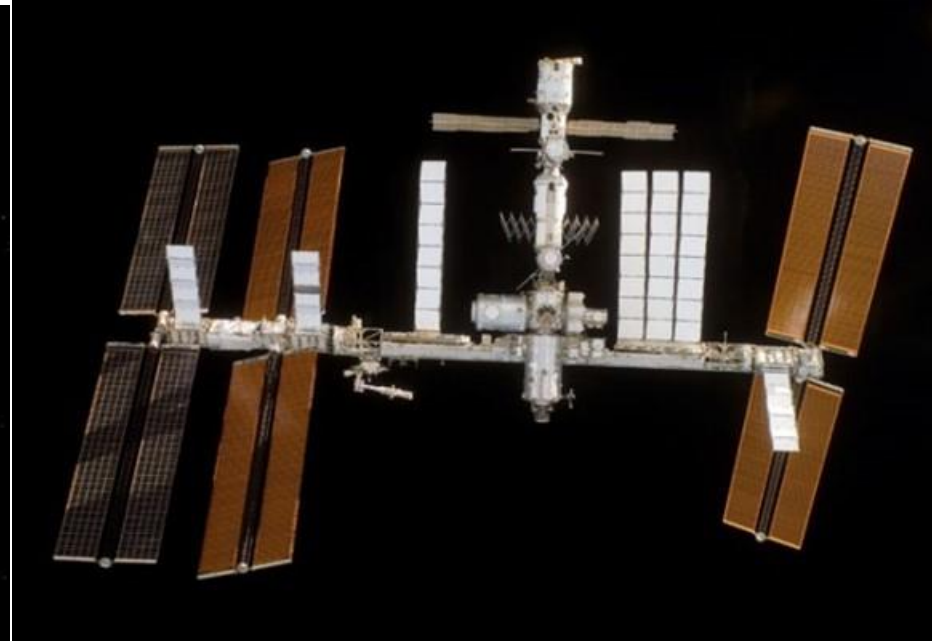
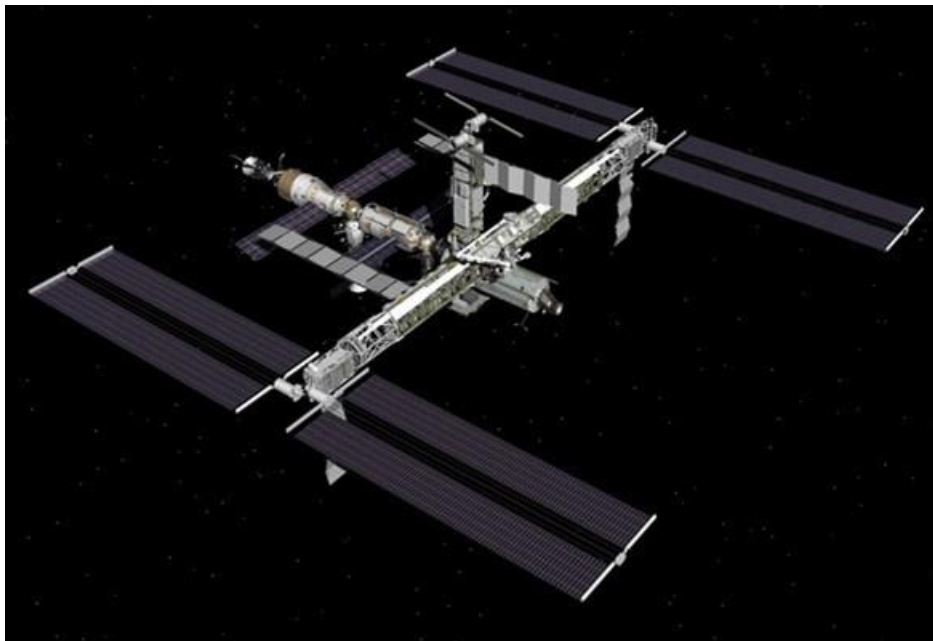
- Robonaut is a humanoid robot with two arms and two legs (in work)
- Each arm has a dexterous, human like hand which enables Robonaut to interface to crew tools
- Each leg has a gripper interface that can attach to handrails to maneuver through ISS or handle payloads with similar handrails
- Robonaut can offload crew from menial or monotonous maintenance and housekeeping tasks

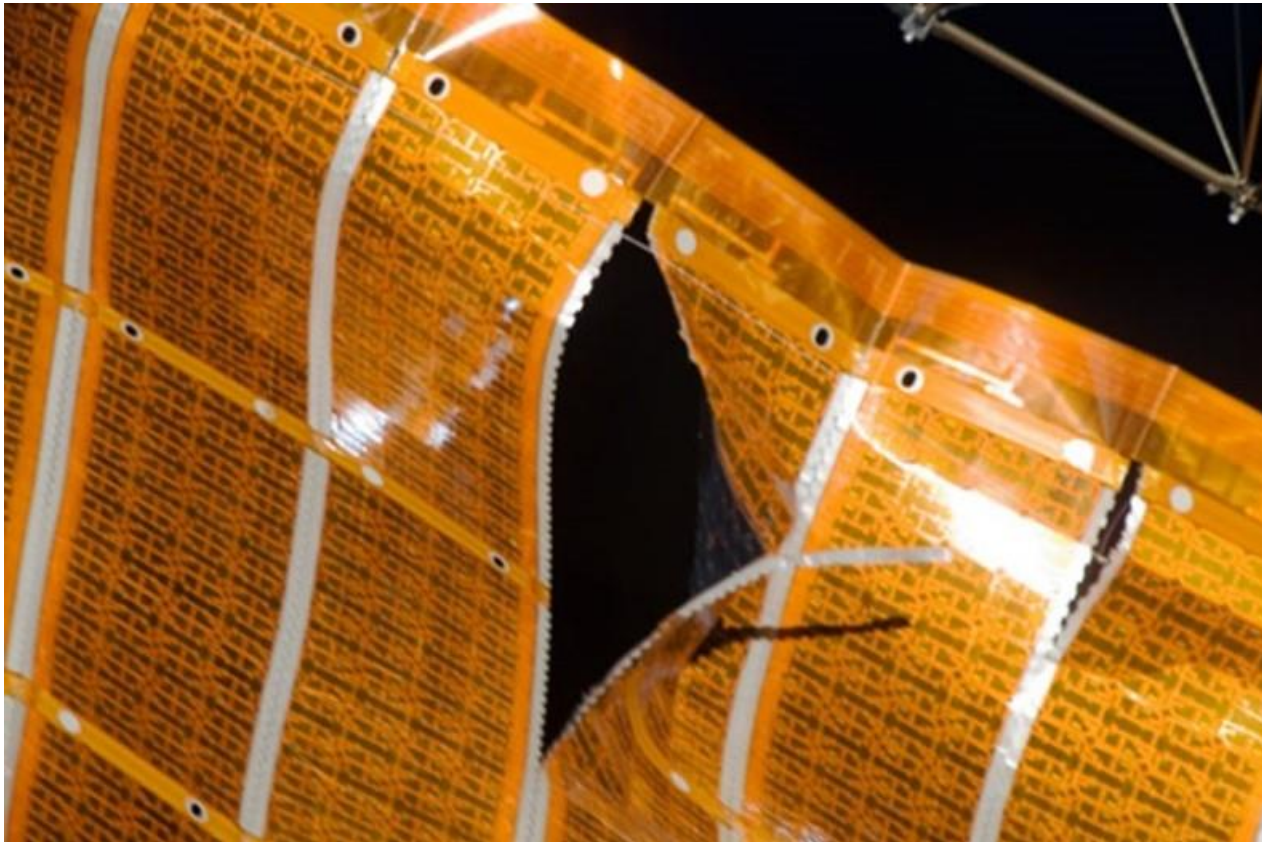


You can't plan for every contingency...



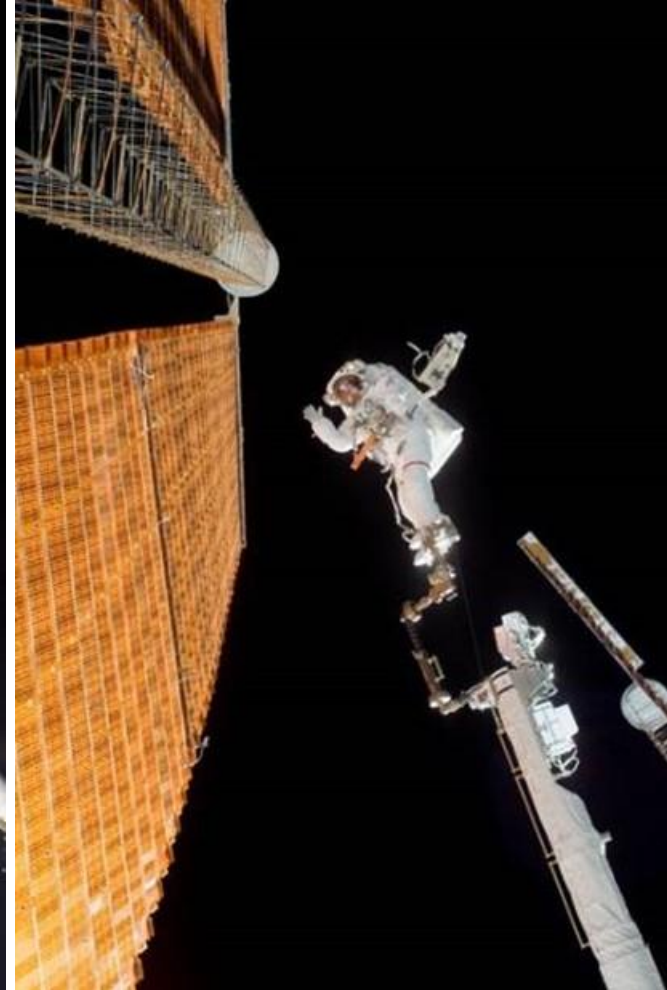
- The Port 6 Truss was the first solar array truss launched to provide power to ISS during assembly
- After the Starboard 4 Truss and Port 4 Truss were in place with their solar arrays providing power, Port Truss 6 arrays were retracted
- On STS-120, the Port 6 truss was moved from ISS center to its final home on the outboard end of the truss
 - On flight day 8, one side of the array was deployed and the other was almost 60% deployed when....





- Solar panel tore ~30 ft up the array!
- Crew couldn't scale the array on their own
- SSRMS couldn't reach the crew to the array by itself
- Shuttle Orbiter Boom (used to view Shuttle tiles) was ~50ft long but SSRMS could only grab the middle interface for ~25ft extra reach

- With the tallest crew member on the end of the boom, it was just enough to allow him to sew the panel back together

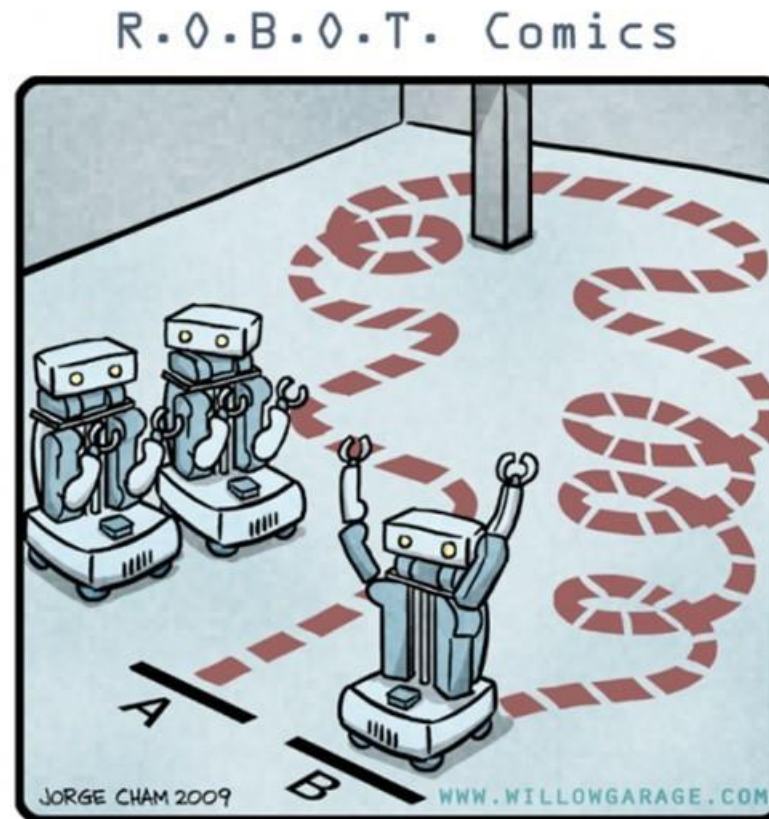


You can't plan for every contingency...
**But sometimes you can make it work if you think
outside the box**

Red and Rover by Brian Basset



Some efficiencies look like obvious advantages...



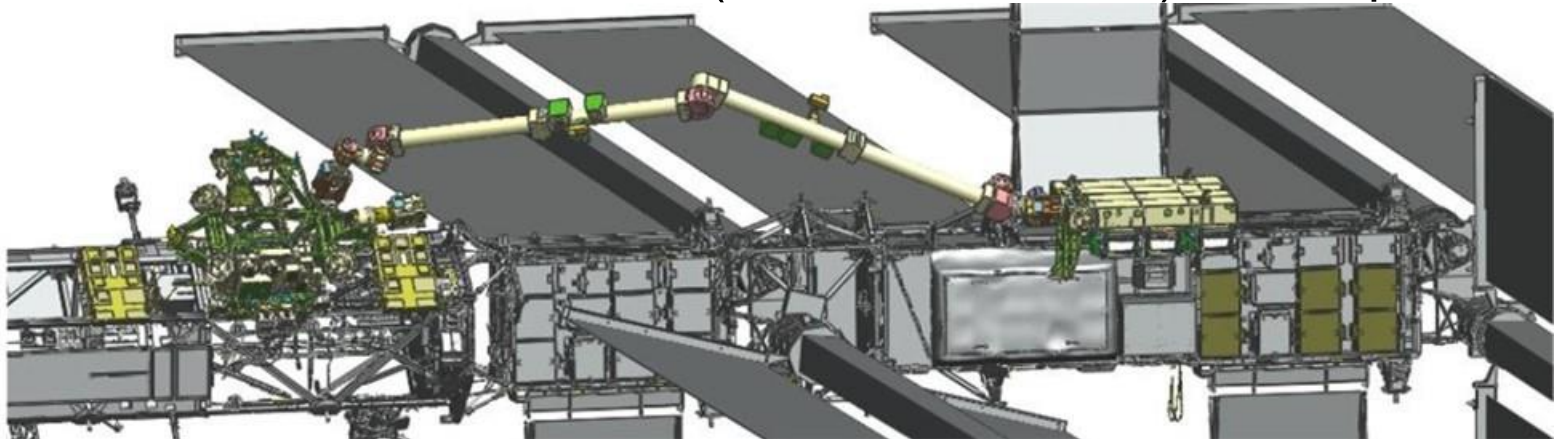
"HIS PATH-PLANNING MAY BE SUB-OPTIMAL, BUT IT'S GOT FLAIR."

- As Shuttle was heading to retirement, Program opted to forgo launching the outboard MBS rails to better utilize the final Shuttle cargo space and save 5 EVAs (each side) to assemble the rails
 - SPDM would no longer be able to assist with repair of 60 outboard boxes including the 48 ISS batteries
 - So far, failure rates were low and better than predicted
- Space Station life was extended beyond the initial planned 15 years out to (at least) 2024



S128E009846

- New life span meant all 48 ISS batteries would need to be replaced
- HTV6 (just completed) and next year's HTV7 utilize SPDM to do the majority of the battery transfer work
 - 18 days of robotics (controlled from ground)
 - 2 EVAs per flight
- HTV8 and HTV9 will bring up the new batteries for P6 and S6 (which robotics cannot reach)
 - SSRMS will be used to get the upcoming pallet of batteries as close as possible to the workspace
 - Requires 6 EVAs per flight
- Failures of the other 12 boxes (we've had 2 so far) also require EVA



Some efficiencies look like obvious advantages...

But they may create inefficiencies later so

Think beyond the Now

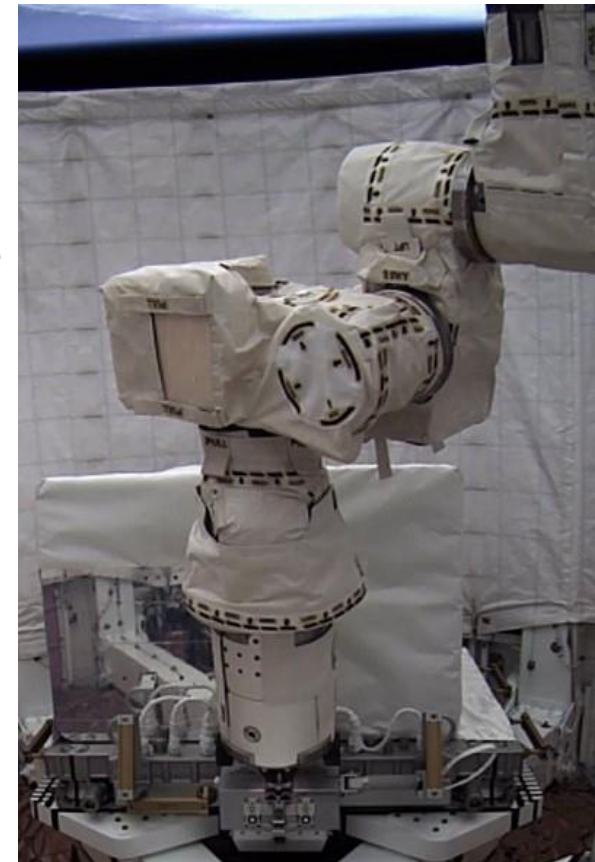
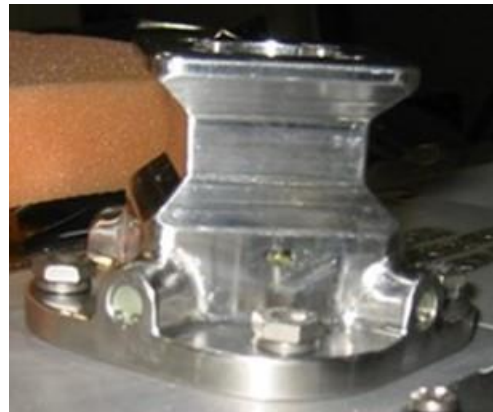
WHERE ARE THE FLYING CARS?
WHERE ARE THE MOON COLONIES?
WHERE ARE THE PERSONAL
ROBOTS AND THE ZERO GRAVITY
BOOTS, HUH? YOU CALL THIS A
NEW DECADE?! YOU CALL THIS
THE FUTURE?? **HA!**



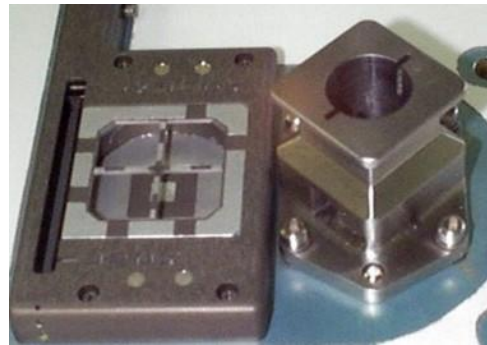
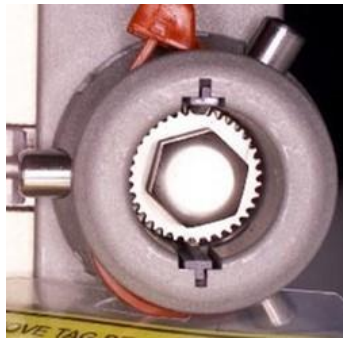
Small things can trip you up...



- Increase ISS Life Span and changing contracts has lead to a variety of manufacturers for robotic interface hardware
- Grasp fixtures:
 - SPDM software assumed a range of grasp fixture sizes based on measured values from early in the program
 - Drawing had a larger tolerance range
- Some new grasp fixtures were within tolerance but outside the measured range in the software
 - Inability to grasp a new payload's grasp interface forced a stand down of operations on SpaceX-3
 - Delay of 4 days while problem was assessed and new software updated



- Collocated bolts and anti-rotation devices:
 - SPDM has a 6-point socket with specific axial force capabilities
 - Has to push past anti-rotation device springs to allow bolt to turn
 - New manufacturers building 'to print' but with 'updated' processes

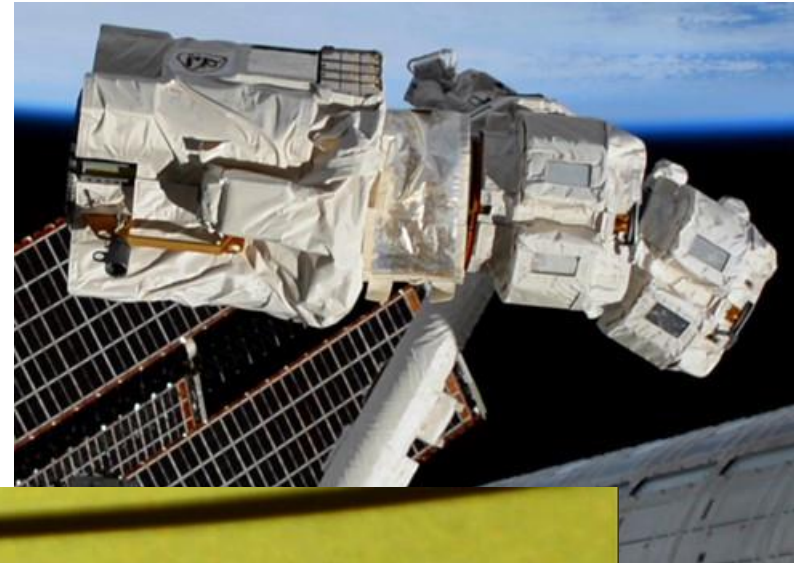


- On HTV6, SPDM and its tools had issues accessing several bolts
 - Could not get tool socket to seat on two bolts (left to EVA to activate)
 - Had difficulties getting sockets off of bolts (risking damage to robot)
 - Still investigating, but could be differences in tolerances on bolts or differences in anti-rotation device manufacturing process

Small things can trip you up...
So design to be more flexible



- Design for repair at the lowest levels first
 - SSRMS End Effector snare cables were getting stuck in 'C' and even 'S' curve shapes; required EVA to lubricate the hinges
 - Snare cable strands are breaking and will eventually not be able to take load; EVA will have to replace the entire end effector (191kg/420lbs, ~4ftL/2.3ft wide)



- Verify the design can work longer than required
 - Analyses tend to only verify to the requirement level but...
 - What if the load is just over the requirement?
 - What if the bolt won't unfasten at the expected torque?
 - What if the hardware is on orbit 10 more years?
 - Countless hours spent during ISS anomalies trying to determine the actual capability of the hardware or if there is a problem with applying a little more force to pull out a box or a little more torque to break a bolt free
 - Ask the questions during design phase to allow for issue tolerance and flexibility later
 - What is the maximum load the design can take?
 - When will the bolt actually yield or break?
 - What is the maximum thermal clock?





For Inspiration and Recognition of Science and Technology



<https://www.firstinspires.org/node/3651> for more info on game
www.thebluealliance.com to view matches for LoneStar North Regional
this weekend (April 1st and 2nd)

FIRST Championship – Houston, April 19-22 at George R. Brown!!

COME JOIN US!!!